History of Electrical Engineering

Otto von Guericke
1602–1686

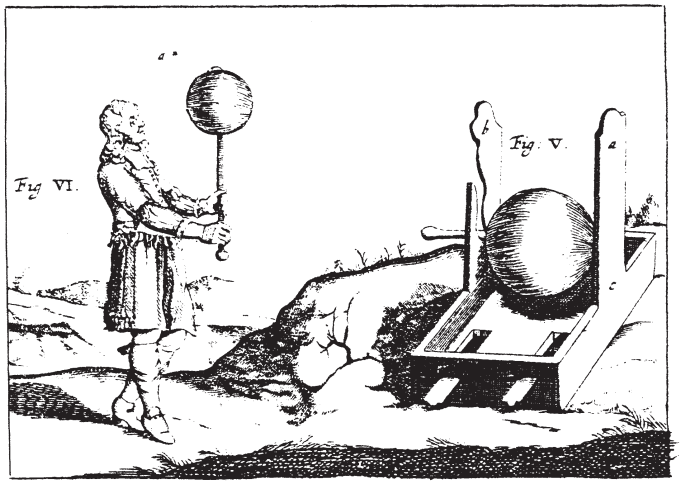
Benjamin Franklin
1706–1790

Allesandro Volta
1745–1827

Written by Bern Dibner

Reprinted with permission from the "Ten Founding Fathers of the Electrical Science"

Otto von Guericke
and the First Electrical Machine



From von Guericke, "Experimenta Nova", 1672.

Although better known for his experiments in determining the pressure of air than for his contributions to the science of electricity, it was Otto von Guericke who devised and used the first electrical machine, an electrostatic generator.

Guericke was active both politically and scientifically in the turbulent times of the mid-1600's; he participated in the disastrous Thirty Years War and was the burgomaster of Magdeburg for 35 years. He invented the first air pump about 1645 and in the following 10 years improved its construction and inspired Robert Hooke and Robert Boyle in England to advance its use. He devised a stack of sealed brass tubes to demonstrate the height at which air pressure will support a column of water. With this, the first water barometer, he demonstrated that variations in the top of the column are associated with changes in weather.

The science of Electricity owes to Guericke a debt for his invention, in 1660, of its first electrical machine. This machine is described by Guericke in his book *Experimenta Nova Magdeburgica,* published in Amsterdam in 1672. Here are also described electrical conduction and electric repulsion, which had been described earlier by Cabeo in 1629. Gilbert had not only failed to notice repulsion, he denied its existence; Guericke recognized the significance of repulsion and experimented with it. He noticed that after the sulphur globe had been electrified by rubbing, a body would first be attracted to it and, on contact, be repelled. If this body then touched any other body but the sulphur globe it would again be attracted to the globe. Guericke had constructed his machine so that the globe on its shaft could be lifted from its supports and carried about the room as shown in the diagram in his book. He observed that a feather floating in the air would be repelled by the globe, that the feather preferred attraction to "the points of any object whatsoever before it, and it is possible to bring it to where it may cling to the nose of any one." Pointed conductors were therefore most effective in attracting an electrified body.

The construction of this electrical machine, the first rotating generator, was basically a sulphur ball revolving on a shaft. The ball was formed by pouring molten sulphur into a spherical glass container. When the sulphur cooled, the glass shell was broken away leaving its spherical form; into this an iron shaft was inserted and the assembly was then mounted on the bearing supports of a wooden frame. When revolved, a dry hand was applied to the revolving sphere. This electrified the sphere which was then shown to attract paper, feathers, lint and other light objects. It was also noted that these adhered to the sphere as it rotated and it prompted Guericke to compare it to objects clinging to the surface of the earth. He thus assigned an electrical cause to the attraction of things to the earth's surface as against Gilbert who believed this attraction to be of magnetic origin. He also noticed that there was agitation in drops of water brought near the electrified sphere and that the attractive effect was dissipated when brought near smoke or fire. Most important of all, Guericke observed small sparks in the discharge and heard their crackling sound. Thus, for the first time, someone actually saw and heard what heretofore had been manifested only as a gentle attractive force. Guericke noted that "if you take the globe with you into a dark room and rub it, especially at night, light will result;" further, "there is likewise a virtue of sound in this globe, for when it is carried in the hand or is held in a warm hand and thus brought to the ear, roarings and crashings are heard in it." Dr. Wall of London, reporting on some experiments in 1708 to the Royal Society, in which he had produced flashes of light and a crackling sound by drawing a long piece of amber through a piece of woolen material, made the prophetic observation that these sparks, some an inch long, resembled thunder and lightning.

With the new machine Guericke observed the *repulsion* of what we would call similarly electrified bodies. One such body which had first been attracted to the sphere was now repelled by the sphere but attracted to other bodies. It was then again attracted to the sphere after having come in contact with a finger or upon touching the ground. He also observed that a feather would move up and down between sphere and ground. Further observation showed that an electrical charge traveled out to the end of a linen thread and that bodies became charged even if only brought close to a charged sphere. The phenomena of both electric conduction and induction were thus observed and demonstrated by Guericke; they became the subject of extensive investigation by later electricians. Guericke had succeeded in "showing ocularly that the sulphur globe, having been previously excited by rubbing, can likewise exercise its virtue through a linen thread an ell (45 inches) or more long, and there attract something." Gilbert had noticed the extension of magnetic influence along a magnetized bar; Guericke

observed the same behavior of the electrical charge along an electrified body.

Thus, by placing a linen thread in contact with the electrified globe, Guericke took the first step in the ever-extending process of electrical transmission of power, albeit the distance travelled was little more than a yard. Stephen Gray, a half century later, extended the span of transmission to over 250 yards of linen thread. It remained for Dufay, writing in 1733, to call the attention of the Royal Academy of Science of France to the importance of Guericke's electrical discoveries.

It must be noted that the work of Guericke, as of his predecessor William Gilbert, rested entirely on a comprehensive series of experiments, ingeniously thought out and keenly observed. The dramatic demonstrations of the pressure of air so overshadowed Guericke's work in electricity that less attention was paid to his electrical experiments by his contemporaries. For instance, one of the most moving demonstrations in the entire history of science was that of Guericke's "Magdeburg hemispheres" made before the assembled Diet of Ratisbon in 1654. In this, he applied two teams of eight horses each to pull apart two copper hemispheres fitted carefully together, from which the air had been exhausted by his vacuum pump. The teams strained but the hemispheres did not part. However, when the stopcock leading to the sphere was opened, the air rushed in and the sphere parted.

Using the Guericke electrical machine as a basis, the curator of instruments of the Royal Society, Francis Hauksbee, built a machine that extended the complexity of electrical display and he published his observations in the first decade of the 1700's. Hauksbee combined Guericke's two foremost contributions to science—his vacuum vessel and rotating sulphur ball—by integrating them into a glass sphere capable of being exhausted, yet mounted on trunions so that it might be rotated. A further improvement was to speed up the rotation of the ball by connecting it by a belt to a larger wheel turned by a crank. When the glass sphere was exhausted by an air-pump, and amber and wool were rubbed in the partial vacuum, a vivid luminosity was observed at the points of friction, remaining luminous as long as the revolving continued.

Beginning with the Guericke electrostatic machine, man's interest in electricity steadily increased. From this first sphere, the size of a child's head, others were built of increasing size and complexity until sparks five feet long were obtained. With these a more exact knowledge of the behavior of the electric charge and electrified bodies was made possible.

Benjamin Franklin

and the Universal Nature of Electricity

There was a span of a century between the activity of Guericke and Benjamin Franklin. In this time several major contributions to the ever-growing interest in Electricity were made, in particular the independent invention of the Leyden jar, or first condenser, by E.G. von Kleist of Pomerania and Petrus van Musschenbroek of Leyden. Before Franklin, materials used in electrical experiments were separated into "electrics" and "non-electrics." The former were those bodies that could be charged by friction while held in the hands of the experimenter, while "non-electrics" included those that could not be so charged.

From an old engraving.

Franklin's interest in electrical phenomena was aroused when he attended a lecture presented by Dr. Spencer of London, in Boston sometime between 1744 and 1746. Franklin was then a man of 40, soon to retire from a successful career as a printer. He immediately purchased all of the lecturer's electrical equipment and began to experiment. The generator of Franklin's day was a glass sphere or cylinder rotated by a crank, and against which a leather, felt, or cloth cushion, sometimes impregnated with a mercury amalgam, would be pressed. An electric charge so generated would be drawn to a metal bar or chain suspended by silk strands and transferred to the metal rod projecting through the cover of a Leyden jar. Such a charge was used to demonstrate before Louis XIV how 180 soldiers of his guard or how 700 monks of a convent in Paris, joined hand in hand, would jump simultaneously when a jar's charge was transmitted through them. From his experiments Franklin concluded that the peculiar property of charged bodies to attract and repel one another was not a manifestation of two different kinds of electricity as believed by the electricians before him, but the transfer of electric fluid from one body to another. With this conclusion Franklin provided a complete understanding of the operation of all forms of condensers and charged bodies. He analyzed the charge in a Leyden jar and found that it always was charged positive on one metallic coat and negative on the other (the very terms "positive," "negative," "plus," and "minus" were his permanent contributions to our electrical vocabulary) and explained the principles of electrostatic induction. He claimed that although opposite in sign, the charges were of equal magnitude and proceeded to demonstrate this by suspending a pith ball equidistant between two wires connected, one each, to the two surfaces of a Leyden jar. The ball oscillated from wire to wire until the charges had equilized and the pith ball hung limp between them. He devised the "Franklin Pane" which consisted simply of a thin sheet of glass on either side of which were fixed thin metal sheets (a parallel plate condenser), and showed that it was the glass that held the charge. He also discovered that charges reside on the outside of a charged hollow conductor, that

when one body contains more than its normal quantity of the electric fluid, a wire connecting it to a neutral or negatively charged body permits the charge to become uniformly distributed between them. If not connected, but placed sufficiently close together, the charge passes between such bodies in the form of a spark.

To Peter Collinson of the Royal Society he communicated his observations and theories about lightning, which were basically that electric charges were raised form the sea and from the land by evaporation. These gathered in clouds of differing charges which, as they approached one another, discharged with a display of thunder and lightning. Therefore, contended Franklin, the action of an electric machine and lightning were similar. He enumerated the similarities thus: (1) the resulting light and sound are similar, and both phenomena are practically instantaneous; (2) the spark, like lightning, is able to set bodies on fire; (3) both can kill live creatures (Franklin killed a hen by the discharge of several Leyden jars); (4) both do mechanical damage and have a smell like burnt sulphur (this led to the discovery of ozone); (5) lightning and electricity follow the same conductors and both pass most readily to sharp points; (6) both are able to destroy magnetism, or even to reverse the polarity of a magnet; (7) both are able to melt metals.

Finally as a result of both theoretical analysis and observations of experiments, Franklin concluded that a sharp pointed object, especially if grounded, was more prone to draw off an electric charge than was a dull, rounded one. Coupling this conclusion with his understanding of the nature of lightning, Franklin conceived the notion of drawing off a lightning charge by means of a tall rod, the top of which terminated in a point and the bottom set in the ground. This became the lightning rod which served not only as a great benefaction in eliminating the hazard of destructive lightning strokes; it also helped popularize Franklin's name on both sides of the Atlantic. The King of France sent a special letter to the Royal Society complimenting Mr. Franklin on his valuable contribution.

To confirm the electrical nature of lightning experimentally, Franklin made his famous kite experiment in June 1752. This he described in a letter to Collinson dated October 1, 1752. A kite of cedar ribs was covered with a thin silk handkerchief to which a sharp pointed wire was added at the top and the usual tail at its bottom. Franklin then added a silk ribbon to the bottom of the twine and at this juncture fastened a key. In flying the kite in a storm, the experimenter stood in the shelter of a door so as not to wet the silk ribbon. He noted that when the thunderclouds cross over the kite "the pointed wire will draw the electric fire from them, and the kite, with all the twine, will be electrified and the loose filaments of the twine will stand out every way and be attracted by the approaching finger." He noted: "At this key the phial [Leyden jar] may be charged, and from electric fire thus obtained, spirits may be kindled, and all the other electrical experiments be performed." He later discovered that thunderclouds may be charged either positively or negatively. De Romas, a French experimenter, repeated Franklin's experiments and succeeded in drawing a spark from the clouds eight inches long. Dalibard (who translated Franklin's book into French) set up a pointed rod at Marly, near Paris, following Franklin's instructions. Here his deputy drew sparks during a thunderstorm in May 1752. The idea spread to England and other nations on the Continent. In 1753, a Prof. Richmann of St. Petersburg was killed by a charge that was brought down an improperly terminated rod; this unfortunate result thus made him the first martyr to the new electrical science. The lightning rod idea expanded in Franklin's mind so that he asked "May not the knowledge of this power of points be of use to mankind, in preserving houses, churches, ships, etc., from the stroke of lightning, by directing us to fix on the highest part of these edifices, upright rods of iron made sharp as a needle, and gilt to prevent rusting, and from the foot of these rods a wire down the outside of the building into the ground, or down round one of the shrouds of a ship, and down her side till it reaches the water?"

With the publication of his book "Experiment and Observations on Electricity, made at Philadelphia in America" in London, 1751, his reputation grew rapidly in Europe. This book was reprinted five times in English in his lifetime and in several editions in French, Italian and German. On his visits to England and France he became one of the most popular men of his time. He received a doctorate from Oxford, was elected Fellow and Manager of the Royal Society of London and was chosen one of the eight foreign members of the Royal Academy of Sciences of France, the only American to be so elected for the next hundred years.

The enthusiasm which Franklin displayed in his electrical research is well demonstrated in his third letter to Collinson. In it Franklin sums up by describing an event to celebrate that fruitful year, 1747, "in a party of pleasure on the banks of the Skuylkil a turkey is to be killed... for dinner by the electrical shock, and roasted by the electrical jack before a fire kindled by the electrified bottle: when the healths of all the famous electricians in England, Holland, France and Germany are to be drank in electrified bumpers, under the discharge of guns from the electrical battery."

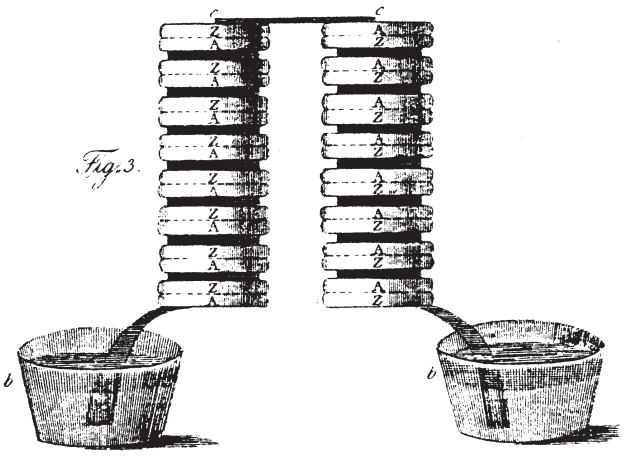
Alessandro Volta

and the Electric Generating Cell

The scientifically fruitful 1700's ended with electricity still in the form of electrostatic discharges, small ones in the laboratory, shattering ones in the form of lightning. At the very end of the century there was introduced energy in a new form, electricity from a chemical source—the electric "pile" or battery conceived by Alessandro Volta.

Beginning his electrical investigations in 1762, Volta improved the electrical equipment of his day by introducing the electrophorus, a kind of reservoir of electricity. It was one of the first electrical machines that operated by electrostatic induction or "influence" rather than by direct electrostatic generation. The device consisted of a plate of resin placed between an upper and lower plate of metal. The upper plate was lifted by an insulated handle and the resin was charged by being struck by a silken scarf. When the upper plate was laid on the resin, grounded by being touched by the experimenter's finger and then removed, it became charged by induction. This device brought Volta's name before the attention of electrical experimenters everywhere. He invented the condensing electroscope; with it, minute quantities of electricity could be detected and it was therefore very useful in the investigations that led to the invention of the pile. It was the publication of the operation of this condenser in the transactions of the Royal Society in 1782 that won him the Society's Copley Medal in 1794 after his election as a Fellow in 1791.

Volta was investigating the recently announced phenomenon of "animal electricity" discovered by Luigi Galvani, Professor of Anatomy at the University of Bologna. Galvani, a shy and retiring scholar, had noticed, while dissecting a frog, that a discharge from a neighboring electrostatic



Volta's bi-metallic pile. From Trans. Royal Soc., 1800.

generator had caused the legs of the dissected frog to jerk. He thereupon tried to trace the relationship of the charge and the muscular action. "While one of those who were assisting me touched lightly and by chance the point of his scalpel to the internal crural nerves of the frog, suddenly all the muscles of its limbs were seen to be so contracted that they seemed to have fallen into tonic convulsions." In 1791 he published his observations and theory, one of the key discoveries in the whole history of science, in the Transactions of the Bologna Academy of Sciences.

Galvani sent a reprint of his paper to a few of his scientific colleagues, including the professor of physics at Pavia, Volta. In a revolutionary period of the world's history, this paper with its startling significance, aroused the interest of scientists everywhere. Volta concurred in the general theory proposed by Galvani and proceeded to repeat the experiments. As these experiments progressed, Volta became convinced that the true electric source lay not in the tissues of the animals investigated but came from an outer source, the contact of dissimilar metals. The controversy between the two schools of thought was resolved when Volta disclosed the nature of the electric cell in a letter written from Como on March 20, 1800 to Sir Joseph Banks, President of the Royal Society of London. In this letter Volta described his new apparatus which he compared in action to the Leyden jar.

Volta observed that the results produced depended on the kind of metals used in combination. He therefore arranged the common metals into a series and using rubbed rods of glass and of resin in order to obtain positive or negative electricity as a reference, Volta combined these metals and established which combination produced the strongest positive or negative charges. Some combinations produced negative, some positive charges. He therefore became convinced that in kind and degree the result depended on the relative arrangement of the mating metals in a series in which zinc proved most positive and graphite most negative, with lead, tin, iron, copper, silver and gold, between those two. Volta could thereby anticipate the strength of a charge in the relative position of the metals in this (electrochemical) series; from this he derived his "law of successive contacts." In its final form, Volta proposed a stack of elements consisting of discs of silver and zinc separated by brine-soaked cloth or paper. Thirty such elements formed this pile and caused a flow of sufficient continuous current to be perceptible to a person touching the outer elements of the pile. A modification of the device was to arrange a row of cups containing weak acid or brine; into each cup a zinc and silver plate was placed; alternate elements were connected by metallic strips; this Volta termed his "crown of cups." This arrangement avoided the weakening of the flow of current that followed when the moisture (electrolyte) dried from the paper or cloth separators in the pile arrangement. He also found copper an improvement over silver in the set.

In his letter to Banks, Volta said that although the new source of electricity was weaker in character than the discharge from the Leyden jar, it did possess the great advantage of offering a *continuous* source of electricity. In fact, felt Volta, his pile of copper and zinc discs could supply an inexhaustible and constant electric flow. His letter states "this endless circulation or perpetual motion of the elastic fluid may seem paradoxical, and may prove inexplicable; but it is nonetheless real and we can, so to speak, touch and handle it" and "I found myself obliged to combat the alleged animal electricity of Galvani, and to declare it an external electricity moved by the mutual contact of metals of different kinds." Since Volta was a physicist rather than an anatomist, the emphasis of his thinking had shifted from the importance of the physiologic elements to that of the metals.

This revolutionary contribution, one of the most brilliant gifts of the human mind, was immediately recognized for its true importance. Volta was invited to Paris to demonstrate his discovery before Napoleon. Experimenters everywhere were now afforded a source of constant flow electricity. They found in these new devices a means of drawing electric current for hours instead of the erratic spark that came from the electrostatic generators or Leyden jars in use for a century.

With this new instrument Nicholson and Carlisle in England decomposed water into its elements and determined the true volumetric ratio of oxygen and hydrogen. Sir Humphrey Davy,** using a large voltaic pile, discovered potassium and sodium. He also drew an electric current from a 500-plate voltaic battery and caused two charcoal electrodes to burn with sun-like brilliance; in this way began electric illumination. With constant-flow electricity the electro-magnet was formed by Arago and by Davy. Thus the last century began punctually with the significant forward move that brought electricity from a plaything of the curious to a most important tool in the hands of mankind.

Succeeding generations of electricians, who best understood the magnitude of Volta's contribution, saw fit to measure electromotive force by the term "volt" as proposed by the International Electrical Congress meeting in Paris in 1881. In his eulogy of his colleague Volta, Arago wrote of the electric battery as "the most marvellous instrument created by the mind of man, not excluding even the telescope or the steam engine."

**See Cover Photo.